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Relationship Between Curing Compounds and Scaling Resistance for Concrete Pavements

Prepared for
WHRP Rigid Pavements Technical Oversight Committee

Prepared by
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WisDOT Research & Library Unit

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Keywords: scaling, scaling resistance, curing, curing compounds, freeze thaw.

Summary

We found 13 citations for documents published in 2002 or later, and one Research in Progress entry. One of the citations was published in 2009, three each in 2008 and 2007, two in 2006, one in 2005, two in 2003 and one in 2002. Two of these reports refer to state DOT studies.

Citations

Links to online copies of cited literature are provided when available. Contact the WisDOT Library to obtain hard copies of citations.

Title: New Performance-Based Approach for Assessment of Curing Effectiveness
Author(s): Shon, Chang-Seon; Ye, Dan; Mukhopadhyay, Anal K.; Zollinger, Dan G.
Date: 2009
Source/URL: Conference Proceeding Paper from Transportation Research Board 88th Annual Meeting.
Description: 18 pages
Contents: Ensuring sufficient water availability in hydrating concrete is of great importance for quality curing relative to both short-term and long-term performance of concrete pavement. Excessive early-age evaporation from the concrete pavement surface can cause high porosity, and low strength at the top part of concrete with a deeper moisture gradient, which ultimately leads for some aggregates to a greater potential of surface distress and warping induced delamination. Application of liquid curing compounds on newly built concrete pavement surfaces has been widely used to minimize evaporation. However, the availability of a reliable test method to assess the efficacy of a curing compound relative to the amount of expected evaporation is still lacking. Therefore, advancements are needed to facilitate the evaluation of curing effectiveness in terms of their expected performance under field conditions. This paper presents a laboratory-based procedure, which bridges laboratory measured parameters to performance in the field, in terms of qualifying the effectiveness of a curing compound membrane relative to the factors that control it. The curing monitor system, a device capable of accurately recording relative humidity and temperature readings at three critical locations along with wind speed and solar radiation is used as part of a

laboratory test procedure to assess the efficacy of a curing compound. A compound curing effectiveness parameter, i.e., effective curing thickness or an evaluation index, as defined in this paper, is then calculated based on the above measured parameters. The curing effectiveness parameter is useful to rank the curing compound relative to specific lab conditions. From the limited field application studies, it has been observed that the proposed test procedure has good potential to evaluate the curing effectiveness under field conditions.

Title: Identification of Compliance Testing Method for Curing Effectiveness
Author(s): Choi, Seongcheol; Won, Moon C.
Date: June 2008
Source/URL: Report from Texas Department of Transportation, http://www.utexas.edu/research/ctr/pdf_reports/0_5106_2.pdf.
Description: 53 pages
Contents: Curing has substantial effects on the long-term performance of portland cement concrete (PCC) pavement. The Texas Department of Transportation (TxDOT) requires two applications of curing compounds, with a maximum 180 sq. ft./gal. per each application. However, no compliance testing is conducted for curing and, from a practical standpoint, compliance with specification requirements are rarely verified. The purpose of this research was to identify simple testing procedures that can be implemented to verify the compliance with specification requirements on curing. To this end, various test methods that appear to have potential for compliance testing for curing were evaluated in the field. The test methods evaluated include penetration resistance, initial surface adsorption, surface temperature, reflectance, relative humidity, and dielectric constant. A factorial experiment was set up for field testing, and the test methods were evaluated in the field. Varying rate of curing compound applications as well as application time was included as variables in the factorial experiment. Advantages and limitations of each method were identified and discussed. Based on the findings, it is concluded that the methods evaluated are neither practical nor accurate enough to be included in TxDOT specifications as a compliance testing. Rather, it appears that evaluating curing compound application rates by measuring curing cart speed could present the most feasible method for compliance testing.

Title: Effect of Mixture Composition and Initial Curing Conditions on Scaling Resistance of Ternary (OPC/FA/SF) Concrete
Author(s): Radlinski, Mateusz; Olek, Jan; Nantung, Tommy E.
Date: January 2008
Source/URL: *Journal of Materials in Civil Engineering*, Vol. 20, No. 10, pages 668-677.
Description: 10 pages
Contents: This paper presents the results of a multiobjective laboratory study on scaling resistance of ternary concrete containing Class C fly ash (FA) and silica fume (SF). Several experimental variables were included in the research and statistical analysis was performed to examine specific effects of each of the variables on the amount of scaling. The first variable studied was the relative amount of FA (20 percent or 30 percent by mass of total cementitious materials) and SF (5 percent or 7 percent by mass of total cementitious materials) used in the ternary cementitious system. The second variable evaluated was the type of initial curing regime. The curing regimes compared included air drying, 3 days under wet burlap, 7 days under wet burlap, and application of curing compound for 7 days. The last variable assessed was the time of exposure to freeze-thaw (F-T) cycles in the presence of deicing salt, which included testing at either early age (14, 17, or 21 days depending on the initial curing regime) or at late age (90 days). The major finding from the research conducted was that the ternary mixtures containing 20 percent FA are much less prone to scaling than the mixtures with 30 percent FA. The mixtures with 20 percent FA were also found to be less sensitive (in terms of scaling resistance) to the initial curing conditions than mixtures with 30 percent FA. The late exposure to F-T cycles in the presence of deicing salt did not significantly improve the scaling resistance of any of the evaluated mixtures, most probably due to differences in scaling mode associated with the exposure times evaluated.

Title: Durability of Concrete Pavements Used for Aircraft Deicing Facilities
Author(s): Van Dam, Thomas John; Peterson, Karl R.; Sutter, Lawrence L.; Smith, Kurt D.
Date: 2008
Source/URL: Conference Proceeding Paper from Transportation Research Board 87th Annual Meeting.
Description: 24 pages
Contents: Observations of some concrete pavement used in dedicated deicing facilities (DDFs) suggest that premature distress may have been occurring, in some cases as soon as 2 to 3 years after construction. A study was funded by the Innovative Pavement Research Foundation to determine the nature and extent of the observed distress and determine what, if any, role glycol-based deicers played in this occurrence. A forensic analysis of concrete obtained from five DDFs found no evidence to suggest glycol-based aircraft deicers are directly implicated in the

chemical or microbial degradation of concrete. The single largest contributor to the distress can be broadly categorized as poor placement and consolidation and/or finishing and curing. Further, the air-void systems were marginal in many cases, with spacing factors at or above the 0.200 mm maximum limit specified in ASTM C 457. In general, current construction practices appear adequate to prevent the construction-related problems observed. Better mixture design and proportioning, improved consolidation, and the timely and thorough application of an effective membrane-forming curing compound would prevent much of the distress observed. Ensuring that a proper air-void system is entrained in the concrete is a more difficult problem, as common test methods only measure the total air content of the concrete and not the adequacy of the air-void system (e.g., spacing factor, specific surface).

Title: Effects of Ground Granulated Blast Furnace Slag in Portland Cement Concrete—Expanded Study
Author(s): LaBarca, Irene K; Foley, Ryan D; Cramer, Steven M.
Date: June 2007
Source/URL: Report from Wisconsin Department of Transportation, http://www.dot.wisconsin.gov/library/research/docs/finalreports/02-14afurnaceslag.pdf.
Description: 87 pages
Contents: This research examined the properties of concrete containing grade 120 slag cement at replacement levels of 0 percent, 30 percent, and 50 percent. The primary concrete properties studied were compressive strength, split-tensile strength, and deicer scaling resistance. Material variations included four sources of ordinary portland cement and two types of coarse aggregate. Strength properties were studied at room temperature and 40°F mix and curing conditions. Deicer scaling resistance was studied for concrete cured under six curing conditions. Carbonation of concrete cured under these six conditions was also investigated. It was determined that concrete containing 30 percent and 50 percent replacement of ordinary portland cement (OPC) with grade 120 slag cement had a decreased initial compressive and tensile strength compared to OPC concrete. However, by 14 days, the grade 120 slag cement concrete strength equaled or surpassed that of OPC concrete. Compared to OPC concrete, the time to reach 3000 psi traffic opening strength was delayed by 1 to 2 days for 30 percent replacement and by 3 to 4 days for 50 percent replacement. Deicer scaling resistance decreased as the level of slag cement replacement increased. Curing methods which limited carbonation produced concrete with the highest level of scaling resistance. Air-cured concrete had higher scaling resistance than concrete cured with commercial curing compounds. The scaling resistance of all grade 120 slag cement concrete was within acceptable limits. Variations in portland cement source caused changes in strength and scaling resistance properties. Variation in coarse aggregate influenced compressive and tensile strengths but did not influence the deicer scaling resistance. Comparisons with previous research on grade 100 slag are included.

Title: Influence of Mixture Design and Environmental Factors on Continuously Reinforced Concrete Pavement Cracking
Author(s): Johnston, Daniel P; Surdahl, Roger
Date: January 2007
Source/URL: *Transportation Research Record: Journal of the Transportation Research Board*, No. 2020, pages 83-88.
Description: 6 pages
Contents: The influence of concrete mixture design and environmental factors on cracking in a continuously reinforced concrete (CRC) pavement was documented on Interstate 90 in Hanson County, South Dakota. A project evaluated three mix designs, which were placed in the eastbound direction in 2005. From the study, it was shown that crack frequency was directly related to the initial concrete temperature as specifically contributed by the aggregate in the mix—and a reduced cement content making a less workable concrete. The study recommends an application of curing compound within 30 min to reduce CRC cracking, and wetting the aggregate stockpiles in hot weather to cool them overnight to reduce concrete temperature. Construction of CRC test sections containing at least 510 lb./cu. yd. of cement with 112 lb./cu. yd. (15 percent cement replaced with 18.75 percent) Class F fly ash is under way to examine the effects of the rate of early strength gain on cracking.

Title: A New Method for Assessment of Curing Effectiveness
Author(s): Ye, Dan; Mukhopadhyay, Anal Kanti; Zollinger, Dan G.
Date: 2007
Source/URL: Conference Proceeding Paper from Transportation Research Board 86th Annual Meeting.
Description: 16 pages
Contents: Ensuring sufficient water availability in hydrating concrete is of great importance for quality concrete relative to both short-term and long-term performance of concrete pavement. Excessive early-age evaporation from the concrete pavement surface can causes high porosity, and low strength at the top part of concrete with a deeper moisture gradient, which ultimately leads to a greater potential of surface crazing and warping induced

delamination. Application of liquid curing compounds on newly built concrete pavement surfaces has been widely used to minimize evaporation. However, the availability of a reliable test method to assess the efficacy of a curing compound to minimize the evaporation is still lacking. Therefore, advancements are needed to facilitate the evaluation of curing effectiveness especially under field conditions. This paper presents a laboratory-based procedure, which has the potential for application in the field, of qualifying the effectiveness of a curing compound membrane relative to the factors that control it. The curing monitor system (CMS), a device capable of accurately recording relative humidity (RH) and temperature readings at three critical locations along with wind speed and solar radiation is used as a potential test procedure to assess the efficacy of curing compound. The calculated curing parameters (e.g., curing effective thickness or curing index) associated with the test procedure are useful to rank the curing compound relative to lab conditions. From the limited field studies, it has been observed that the test procedure has a great potential to evaluate the curing effectiveness under field conditions.

Title: Guide for Curing of Portland Cement Concrete Pavements, Volume II
Author(s): Poole, Toy S.
Date: August 2006
Source/URL: Report from Federal Highway Administration.
Description: 170 pages
Contents: Information on the current state of knowledge of curing hydraulic-cement concrete and on current curing practice was gathered by means of a literature review and a review of current standard guidance. From this information a draft guide for curing hydraulic-cement concrete pavements was developed. Draft guidance was based around type of curing used (water added, water retention by sheet, or curing compound) and around temperature effects. As a result of review by the project technical advisory panel, additional information was gathered from existing sources on several subjects. Laboratory studies were conducted on topics for which information was needed but not currently available. The result of the investigation was a set of guidelines that focused particularly on attention to details of moisture retention and temperature immediately after placing (initial curing period) and on details of selection of materials for final curing and determining when to apply final curing. Test methods for evaluating application rate of curing compound and effectiveness of curing were also reported. A separate report (FHWA RD-02-099, “Guide for Curing of Portland Cement Concrete Pavements, Volume I”) has been written that captures the details of the recommended guidance. That report is intended to be the principal technology transfer medium.

Title: Evaluation of Pavement Curing Effectiveness and Curing Effects on Concrete Properties
Author(s): Wang, Kejin; Cable, James K; Ge, Zhi
Date: May 2006
Source/URL: *Journal of Materials in Civil Engineering*, Vol. 18, No. 3, pages 377-389.
Description: 13 pages
Contents: This research was conducted to understand the effects of curing compounds and their application methods on concrete properties. In the research, three different curing compounds were selected and applied to lab and field concrete at different times. The curing compounds were applied with two methods—single- and double-layer sprays. Moisture content, electrical conductivity, sorptivity, and strength tests were performed to investigate the effects of curing on concrete properties, especially on the near-surface layer concrete properties. The experimental results indicated that for pavement without curing compound, the properties of the near-surface layer were considerably different from those of the internal layers. By decreasing the differences between the layers through proper curing technique, a pavement would have more uniform properties throughout its depth. Based on the results, the test methods for quantifying concrete curing effectiveness were also evaluated.

Title: The Development of High-Performance Concrete for Transportation Structures in New Jersey
Author(s): Suksawang, N.; Nassif, H.; Capers, H.
Date: 2005
Source/URL: Conference Proceeding Paper from the Seventh International Symposium on the Utilization of High Strength/High-Performance Concrete, pages 838-848.
Description: 11 pages
Contents: A study was performed to develop high-performance concrete (HPC) mixes and specifications for transportation structures using resources that are readily available in New Jersey. A total of 87 mixes with the water-to-cementitious (w/cm) ratio ranging from 0.27 to 0.55 were developed. Both mineral and chemical admixtures—silica fume, fly ash, superplasticizer, and air-entraining agent—were used to improve the mechanical properties and durability of concrete. Out of these 87 mixes, three mixes with different compressive strengths were selected as base mixes. Both the mechanical properties and durability tests were performed on these mixes, which consisted of compressive strength, modulus of elasticity, drying shrinkage, creep, freeze-thaw durability, chloride permeability,

and scaling resistance. Moreover, the effect of curing methods (dry, wet burlap, and compound) on the strength and durability of HPC were also investigated. Results show that the strength and durability of HPC could be enhanced with ternary blended mixes.

Title: Effectiveness of Portland Cement Concrete Curing Compounds
Author(s): Whiting, N. M.; Snyder, M. B.
Date: 2003
Source/URL: *Transportation Research Record*, No. 1834, Concrete, pages 59-68.
Description: 10 pages
Contents: Many different spray-on compounds are available for curing concrete, including newer products that are intended to address the environmental concerns associated with high volatile organic compound (VOC) contents. A laboratory study was conducted to examine the effectiveness of different types of curing compounds in retaining water for hydration, promoting concrete strength, and reducing permeability, relative to classic curing techniques such as plastic sheeting and ponding and relative to the use of no curing treatment. Comparisons of moisture loss, compressive strength, permeability, and capillary porosity were made for samples representing three high-VOC curing compounds, three low-VOC curing compounds, water curing, and plastic-sheet curing, and for samples with no curing treatment after 3 days and 28 days of curing. The performance of the six compounds tested varied greatly, but none of the compounds performed as well as the samples cured with water or plastic sheeting. All compounds performed better than samples with no curing treatment.

Title: Effect of Curing Methods on Early-Age and Drying Shrinkage of High-Performance Concrete
Author(s): Whiting, N. M.; Snyder, M. B.
Date: 2003
Source/URL: *Transportation Research Record*, No. 1834, Concrete, pages 48-58.
Description: 11 pages
Contents: Many engineers and agencies have observed that the field implementation of high-performance concrete (HPC) is highly dependent on curing and placing conditions. The effect of curing conditions on the early-age properties and long-term durability of HPC is not fully understood. There is a need to expand the knowledge of early-age properties and of the effect of pozzolanic material (like silica fume and fly ash) on drying shrinkage. Results are presented of a study performed to identify the effect of various curing methods on the early-age (autogenous) as well as drying shrinkage of normal and lightweight HPC. The study included a comparison of available analytical models for predicting early-age and drying shrinkage with results from tests performed on different mixes. HPC mixes were developed and evaluated as part of an overall study for the New Jersey Department of Transportation to develop and implement mix designs and technical specifications for HPC transportation structures, such as pavements and bridges. The effect of using three different curing methods on the early-age performance of HPC is presented. The curing conditions consisted of air-dry curing, burlap or moist curing, and use of a curing compound. Results show that moist (burlap) curing should be applied within 1 h after the placement of concrete to improve early-age performance. For very low water-to-cement plus pozzolan ratios, fly ash and lightweight aggregate improved the autogenous shrinkage performance. Moreover, current shrinkage models need to be revised to address HPC mixes.

Title: Concrete Curing and Its Relationship to Measured Scaling in Concrete Containing Fly Ash
Author(s): Olek, Jan
Date: July 2002
Source/URL: University Paper from Purdue University,
http://cobweb.ecn.purdue.edu/~concrete/weiss/publications/r_conference/RC-019.pdf.
Description: 22 pages
Contents: The use of pozzolans or supplementary cementitious materials can result in numerous potential benefits. However, concerns over slow strength development and scaling may result in state departments of transportation (DOTs) imposing limitations on the use of supplementary materials in the late fall construction season. This paper describes a series of laboratory tests that have been conducted to assess the influence of curing on the scaling resistance of concrete containing fly ash. This research is being conducted to better understand the role of moist curing and drying on the salt scaling resistance of these materials. The scaling behavior of a typical concrete paving mixture was monitored under less than ideal curing conditions. Reducing the moist curing period results in the concrete microstructure remaining more porous. Results of this study illustrate that excessive drying (especially in poorly cured specimens) may enable an increased volume of salt solution to be absorbed thereby exasperating conditions for scaling by developing concentration gradients in the top surface of the material. Scanning electron microscopy was used to illustrate that this porous weak layer of mortar may develop when water reducing agents are used. Experiments appear to indicate that once the surface layer scales, further exposure to freezing and thawing

cycles results in only limited scaling. The influence of evaporation and curing compounds on reducing scaling is also illustrated and their benefits are discussed.

Research in Progress

Evaluation of High Performance Curing Compound on Bridge Decks
Principal Investigator(s): Hanning, Chris, Arkansas State Highway and Transportation Department
Start Date: July 2009
RIP URL: http://rip.trb.org/browse/dproject.asp?n=23477.
Sponsor Organization: Arkansas State Highway and Transportation Department
Contents: The objective of this research project is to investigate the possible use of high performance curing compounds that are easier to use, give better results and are more economical than standard curing compounds and procedures that are currently being used. A high performance curing compound would be applied to a section of a freshly placed bridge deck while a conventional curing compound would be used on other sections. The deck would then be monitored and evaluated for cracking and the results for each type of curing compound would be compared. If the high performance curing compound performs better than the standard curing compounds, then a new construction specification could be written to include the use of high performance curing compounds in the construction of future bridges.